SOILS OF THAILAND.[1]

Illustrated with Photographs by the Author,

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Too often it has been supposed that all soils growing any one ordinary crop are about the same and that they will respond in approximately the same way to cultural and fertilizer treatments. For instance, it is very common to speak of "padi"* or "rice soils" and it seems to be taken for granted that all soils growing rice are the same or at least they are very similar. This is illustrated in the case of the experiments mentioned below, where the failure to distinguish between different soils has retarded by at least a decade the use of fertilizers on extensive areas of infertile rice soils in the central plain of Thailand—soils which may reasonably be expected to give a marked and distinctly profitable response to suitable quantities of appropriate fertilizers.

About a decade ago two sites were selected for fertilizer experiments on rice in the central plain. I was privileged to see the confidential report of the results of the experiments, but that was before I had become familiar with most of the important paddy soils of this plain. Even so, I could not then understand how on soils presumed to be representative of the main plain there was but a small increase of paddy yields following the application of fertilizers. I did not then know what the soils were like where the experiments had been conducted. However, on the basis of the results reported, it was reasonable to conclude, as it was concluded, that the use of fertilizers on those

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* Padi or paddy is used in different ways. This term may refer to rough, unhusked rice; in this paper padi (plural padis or padies) is more often used to designate the small individual fields of a fraction of an acre or so, the shape and size depending upon the topography and the property lines. Except where there is general flooding and special deep water rice is grown, each field is surrounded by low dykes to hold the water on the land while the "lowland" or "wet" rice is growing. This term padi is never used for upland (unflooded) rice land.

rice soils would be quite unprofitable. The error on the part of the experimenters was to presume that the soils on which their experiments were laid out were representative of the region as a whole. As soon as I visited the localities where the experiments had been carried out, I clearly understood why these experiments gave such a noticeable lack of response to the fertilizer treatments. The soils of these localities are much more productive of paddy than are the average paddy soils of the central plain, for the soils used for these experiments are of the relatively very much more recent alluvium.

Now, if those selecting the sites for these experiments had been trained to distinguish soil differences in the field or if they had had a soil map of the region to consult, or had been able to get the help of one skilled in the field interpretation of soil characteristics to select the sites, they could and no doubt would have had sites on paddy soils not many kilometers distant to the south which would have been much more representative of paddy soils in the central plain as a whole; these without any doubt very badly need fertilizers to produce even a modest yield of rice. What is most important is that if the experiments had been located more logically on the poorer paddy soils of Thailand, then certainly very different results from such experiments might by this time have radically altered for the better our rice agronomy practices. It is hardly necessary to add that not only plant food, but too little, too much or inadequately controlled water for irrigation of rice is an important limiting factor in obtaining a satisfactory crop, even in those areas already served by irrigation canals.

As has been implied, the skilled and experienced soil scientist can readily distinguish many different sorts of soils in the field, particularly if a pit is dug in the soil a meter or more deep, thus exposing a section down through the surface soil and the underlying materials. Soils with particular sorts of profiles are entities which can be recognized just as easily as one recognizes one's friends, though as yet adequate comprehensive descriptions of soils which will enable others to identify the soils described are very unusual. This is partly because we still lack a sufficiently precise and generally established terminology, and partly because soil differences are subtle. Personal acquaintance with soil profiles in the field is even now the really

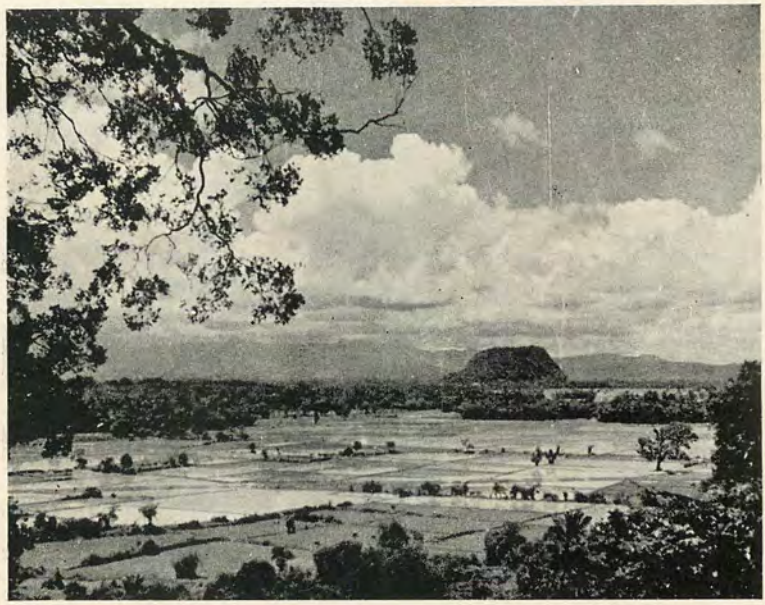

Fig. 1. The Patalung paddy plain west from a limestone bluff, Kao Wan Nieng. Preparation for transplanting rice is under way in the flooded fields. Note the limestone bluff in the distance; beyond is the central mountain range of the peninsula. Patalung province, southern Thailand. October 1936. (RLP 687-.5)

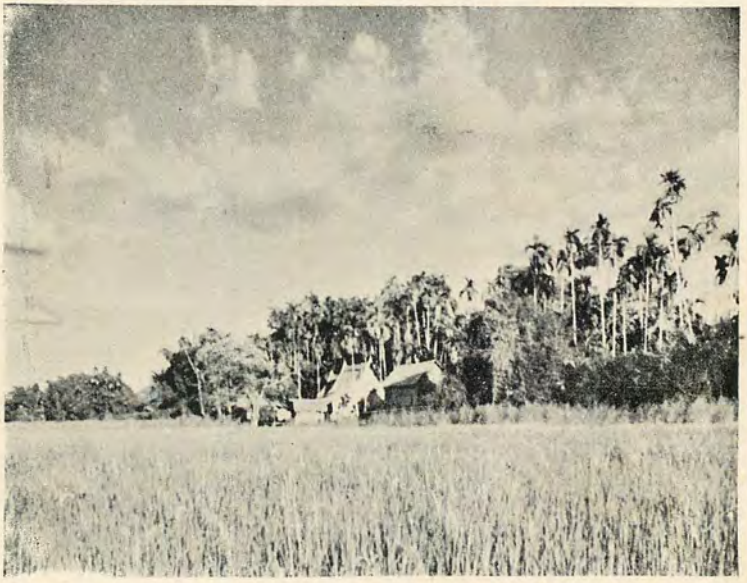

Fig. 2. On the sandy barrier built up by the sea has grown up a village with this Wat (temple) and the groves of palm and fruit trees. The rice in the foreground is growing where there had been a lagoon now filled with soil. Ban Pae, Rayong province, South-eastern Thailand, November 1936 (RLP 725-4.)

only certain way of knowing and distinguishing the different kinds of soils, just as meeting a person face to face is the easiest way of recognising him again, and just as from a description of his features alone it is usually very difficult for one person to be able to identify another person. In the case of people, however, finger printing is conclusive identification. Unfortunately we have not learned how to "finger print" soils, so that thus far there is no known substitute for extensive travelling by soil scientists to see the soils as they exist in the field. But on the basis of field studies it is not only possible to identify the separate types, but often it is possible to group these types into families or other categories, to indicate the broader relationships.

For the field study of soils some sort of digging tools are necessary, inasmuch as not only must the surface soil be inspected, but also that which lies below the surface also, for a meter or more. Seldom can there be found freshly dug wells in good locations or other excavations with exposed profiles. Of course all possible excavations such as railway cuts should be examined, but usually it is necessary to dig pits specially for the purpose, and a short handled shovel and small pick are very useful. The same pit is often used for the collection of the soil samples representing the several horizons or layers of the soil. To get a rough idea of the soil quickly in the course of a soil survey, a soil auger is frequently used, but the auger can never take the place of suitable excavations, for the soil auger not only destroys most of the characteristic structural features of the soil horizons, but otherwise confuses the picture.

Something in the same way that a slice of layer cake shows the different layers, from the frosting down through all the layers and the fillings, a monolithic block of soil, cut out of the soil profile from the surface downward and preserved intact, is of extremely great value in comparing and identifying soils and might save much travelling. A set of such monolithic samples to represent all the soils of this Kingdom would be of great interest and help in the study and understanding of our soils, but it is difficult, tedious, and expensive to collect and preserve intact blocks of soil from the surface down to a depth of a meter or more. Collecting such samples requires more time and skill than we as yet have at our disposal in our Department.

Moreover, the transportation of such samples intact from the place of collection to headquarters is also difficult. Once such samples become broken up their value is very largely destroyed.

Soil Survey.

In order that all the knowledge of the soils, especially their crop producing capacity and adaptations to certain varieties of crops and the results of agronomic experiments such as the responses to certain quantities and amounts of fertilizers, can be effectively interpreted and utilized for more effective soil use and management, it is necessary to classify the soils region by region, or by other suitable areas, such as provinces (čhangwats), and to delineate upon a suitable base map the bodies of soils so classified. A written and illustrated report normally accompanies the soil map and thus explains the data presented in condensed form by the map itself.

A soil survey is not a survey in the ordinary sense of the term, nor is a soil surveyor a surveyor of the ordinary sort. But since there is no effective way of showing the soil classification of a region and making useful the data about the soils of a region other than by the use of a map, frequently the soil surveyor must first make a base map, in which case he does become a surveyor somewhat nearer the popular idea of surveyor, even though the methods of map making he uses are very much simplified. His principal instrument is a plane table, by the use of which he can rapidly draw the map in the field, for triangulation is done graphically, while plotting of details is greatly facilitated. He usually measures distances with an odometer on a buggy or motor car wheel, or by pacing. In spite of seeming over-simplification of method, great pains are taken to make the base map correct and on a large enough scale so that each farmer can locate his lands, and with the help of the agricultural extension agent can get the most out of all the soil studies made upon these or similarly classified soils in the same or other areas. Well I remember the trials of base map making, particularly during the days of my apprenticeship in the U. S. Soil Survey, when I had to drive the horse myself and at the same time count the revolutions of the buggy wheel, by means of a tally punch, and also, as I drove along, make and record all the other observations needed for a good base map.

Fig. 3. During the low water season tobacco and vegetables are planted on these light river bank soils. Confined by bamboo booms *pak bung* (*Ipomoea reptans*) grows well in the river water. Mangoes and other fruit trees about the houses. Just behind these farmsteads lies the rice plain (Fig. 4). Menam Noi, Amphur Putong, Angthong Province, central Thailand, February 13, 1940. (RLP 1218-4.)

Fig. 4. A hundred metres or so back from the river banks in central Thailand (Fig. 3) are these clay plains, on which deep water or floating rice grows very tall if the water is very deep. The boy at the extreme left is standing at the root of one plant, while the boy at the extreme right is standing at the tip of the same plant, where the heads of rice were cut off. Note the dense mass of straw, which must be burned before the land is plowed. Angthong Province, central Thailand, February 1940. (RLP 1213-5.)

When a motor car chanced along, there were additional complications ! It usually took much more time and effort to make the base map than to map the soils themselves.

Now that aerial photography and map making direct from the photographic negatives have been perfected, the tedious days of plane tabling are past, at least in the U. S. A. Enlarged aerial photographs on a definite scale conveniently mounted on cardboard are taken directly into the field and very accurate mapping of soils and other agronomic conditions, such as land use, slope of the land, and amount of soil erosion, is done directly upon these prints. Meanwhile from the photographic negatives base maps of the region have been under preparation in the drafting room, so that as soon as the soil survey and related data are received from the field they are transferred to the completed base map. Thus the soil surveyor has been freed from map making, but since he is now required to map so many other factors relating to the soil, and in much greater detail he is not always glad of the change !

And now that the airplane has begun to be used for study of soils and related conditions, we look forward to the time when we in Thailand may be enabled to do more of our work from the air, as well as to be able to use aerial photographs for base map making to supplement and to reduce the proportion of the very tedious ground work needed now to enable us to properly map and thus understand our soils.

As yet in this Kingdom we have almost no detailed soil survey except the few of the branch experiment stations of our Department. Nor do we have as yet completed any comprehensive reconnaissance surveys. Most of the information which we have been able to gather about the soils of this country is very fragmentary and scattering, for much of it has been gathered more or less incidentally in the course of trips made for other and rather specific purposes. This has also necessitated a different method of soil sampling, for in place of first making a proper soil survey of a limited area, and then collecting the best possible samples of soil to represent the different soil types which have been found to be important as the result of that survey, we have been going here and there, travelling along main roads and trails, along rivers and canals, and only from time to time have we

stopped to collect samples of the soils which seen, as we passed, appeared to be typical and thus important soils of the region; some unusual sorts of soils have also been collected, particularly for comparison with the more important sorts.* Because of the great interest of temperate countries in laterite, a study of this material as it is found in the soil and as it has been utilized for construction purposes in this Kingdom, has become one of my hobbies. All that can be said of such rapid reconnaissances and scattered samplings is that they are better than no soil survey at all, but often not much better!

However, in spite of the handicaps, chief among which is the inability to concentrate on soil mapping, we are gradually extending our knowledge of the soils of Thailand and filling in some of the bigger blank spaces on the soil map, for we are making more trips all the time, and at least a number of trips recently made have been into regions new to us. Even so, here and there fitting bits of additional soils information into the gradually developing scheme of things in widely scattered parts of the country is not nearly so easy as a thorough and more consistent mapping of more limited regions would be. But thorough mapping on a detailed scale is entirely beyond the as yet modest resources of our Department for such work.

To make a detailed soil survey of all Thailand on about the same scales and with about the same degree of accuracy and detail in mapping the soils as have been used by the United States soil survey would require the full time of one soil survey party (consisting of myself and several assistants, including apprentices, draftsmen, clerks and other staff) for several hundred years! But with a high class vertical aerial photographic mosaic of the entire country, the time needed would be greatly reduced.

Now before considering the principal sorts of soils in Thailand, let us consider briefly a few important basic principles of soil character and how the different features of soils develop. The time thus spent will, I hope, be more than made up for in a better understanding of the soils described below.

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*As the Dept. of Agriculture and Fisheries has no Soil Chemistry Laboratory, the Laboratory of the Division of Agricultural Science, Dept. of Science, makes our chemical analyses for us. Their generous assistance is deeply appreciated.

THE DYNAMIC CHARACTER OF SOILS.

There are many different kinds of soils and these soil differences are of many sorts. Some are of very great importance in plant production; others apparently have no effect upon plants. If one understands something of the processes taking place in the soil, and how these soil differences came about, it is possible to appraise rather accurately the characteristics of the soil; such as whether or not during much of the year the land is flooded, and whether or not there is much or little reserve plant food in the soil, what kinds of crops will probably do well, or can not be expected to do well on a certain soil. An experienced student of soils in the field, a soil scientist can, as the result of such field studies, usually judge more accurately than can a chemist in the laboratory the crop producing potentialities of soils, though for the best and most thorough understanding of soils, the findings of the chemical laboratory are essential to supplement the field data. The field studies commence with the detailed examination of the soil profile. And if the profile of an apparently normal soil cannot be found, an excavation must be made for this purpose. When a section down through the surface soil and the deeper material is exposed normally, differences in color, in texture, and structure are to be observed. Frequently in this way we may note vegetable litter, perhaps on the surface, a somewhat darker color for a number of centimeters, then a brighter, lighter color; below this there may be blotched or mottled brown on a gray background or red on a light bluish ground, and in these humid tropics perhaps there is a zone of iron concretions or a solid mass of cellular or concretionary iron compounds. The average person calls these different zones or strata "layers," though it is seldom that the different sorts of material noted have been deposited successively in layers. Rather, in average soils these "layers" have developed in the soil as the result of the climatic and consequent biological factors (rain, heat from the sun, micro-organisms, the roots of higher plants, and the waste products of plants), acting upon the rocks or other material from which the soil has been and is being developed. Even if man does not interfere, the soil is not static, but IS CONTINUALLY CHANGING, the weathering processes are still going on, and will continue to go on, the colloids will continue to be carried downward, iron to precipitate

into concretions and to lock up with it the phosphorus, etc. On the basis of extended studies in the Netherlands East Indies, Mohr has discussed well the dynamic character of tropical soils. He has also clearly shown that the nature of the climate, i. e. whether it is continually rainy, or whether there are longer or shorter dry periods occurring annually, markedly affects the nature of the resulting soil profile. The rainfall regime and the elevation above sea level, which control the prevailing temperatures, also determine the particular types of vegetation prevailing. The type of vegetation and the waste organic matter from it, which may or may not accumulate on the soil surface, depending upon the conditions, markedly affect the nature and the rapidity of the soil weathering processes, and thus the nature and the scale of the soil profile. The slope of the land surface is also very important, for even without catastrophic erosion soils gradually erode off as well as modify the profile development which takes place. Another important effect of slope of the land surface is to determine the amount of rain water which penetrates the soil. If the land be level water stands long on the surface and a certain characteristic weathering type results; while if the land has a considerable slope most of the water may run off. At least such a soil will contain much more air much of the year in place of being saturated with water, and another group of weathering processes comes into play, so that very different sorts of profile forms result.

The weathering processes are going on slowly but continually, thus *time* is an important factor in the development of soil profiles; and is so in determining the present character and probable future nature of any and every profile. Mohr has pioneered by introducing time into a schematic representation of the development of the laterite profile. However, since most of the weathering processes are very slow according to the human conception of time, it is not often possible for a person to note changes taking place nor has it often been possible to satisfactorily reproduce in the laboratory at an accelerated rate, profile development; hence their interrelations can only be inferred.

The Role of Parent Materials in Soil Formation.

Under a given climate on a given slope, and with a given complex of plant forms or associations, a definite sort of profile "will *tend* to

Fig. 5. Great quantities of excellent bananas are grown in the environs of Bangkok, central Thailand, in gardens like these, where the land has been raised, leaving between the beds broad deep ditches filled with water. Young orange trees are growing between the banana plants, which in time will be cut out, leaving the orange trees. Nontaburi Province, central Thailand, September 1937. (RLP 830-5.)

Fig. 6. Notwithstanding the 40 mm. rain which had just fallen, this red clay soil of the Khao Ngua pepper district, Tamai, Chantaburi province easily works into excellent tilth. Chemically, however, the soil is very poor in plant nutrients and quantities of manures must be used to produce good crops of pepper.

develop," whatever the parent material may have been to start with. For example, under a more or less continuously wet climate and heavy rainfall, very similar red, very friable clays have developed on the dark igneous rock in Tamai, Chantaburi, and on limestone in Trang, neither of these rocks having any appreciable amount of quartz in them. Similarly, provided the water table remains near the surface, erosion is absent, and where there has been sufficient time, if there is even a very modest amount of iron in the parent materials, and there is a considerable rainfall, laterites will develop whether the rocks be sandstones, basalts, granites or alluvial materials.

On the other hand in the one Amphur of Tamai, there is not only the red soil (Fig. 6), extremely useful agriculturally, but near by from the quartz-rich sandstones there have developed the light colored, light textured fine sands and fine sandy loams which are very poor in plant nutrients and are less often cultivated. And not far away, in a neighboring amphur there have developed light brown to white coarse sandy soils; while the flat paddy plains just in from the salt water swamps are dark gray clays with light bluish gray subsoils developed from the very much mixed materials carried out from the interior by the streams. Where there has been enough iron in the parent materials and where the water table has been near the surface for a sufficiently long time and where there has not been much erosion, at least until after the profile was well developed, laterite profiles have developed.

GEOLOGY AND GEOGRAPHY OF THAILAND.

Thus we see that, to better get an idea of the soils of Thailand, we must have some conception of its geology and of its topography. The geology will tell us of the parent materials from which the soils have been developing; while the geography, particularly the topography, will indicate where transportation of material and what material has been taking place; where there is much erosion, and where little or none; where dark colored igneous rocks have come to the surface, and where sandstones and granites have been the parent materials of the soils; where limestone and marl are abundant, and

where they cannot easily be had for agricultural purposes, etc.[1] From the soils point of view, as well as culturally, the most important single fact in the geology of central Thailand is that tectonically the central plain has been practically static, i. e. free for centuries from serious earthquakes. There have been no sudden changes in base level, so that the rivers in the central plain are neither cutting down their beds deeper nor has there been submergence of the plains; consequently neither erosion with its concomitant lowering of the water table, nor deposition of large quantities of sediment have been recent disturbing factors in the soil profile developmental processes of the soils in this region. Culturally, the absence of earthquakes in the central plain has meant the preservation of the beautiful and unique architectural monuments of Bangkok and the surrounding country—built on mud. Even a relatively slight earthquake shock in the underlying rocky basin would so violently shake the surface soil of Bangkok that it would almost certainly mean the complete wrecking of most of our beautiful brick buildings; properly designed and built reinforced concrete structures, however, should not suffer any serious damage.

Because of the large amounts of weathering products overlying the rocks in a great part of Thailand, and because of the paucity of fossils or other means of exact identification, the geological age of the rocks of this country is as a whole not very certain. There are believed to be representatives of the following periods: Precambrian, Permocarboniferous, Mesozoic, Tertiary, and Pleistocene. While the geologic age is not important the nature of the rock itself is. This is clearly shown in the Korat region, where the vast extent of the unfaulted red sandstones of the Mesozoic has given rise to important areas of fine sand and similar sandy soils which are not usually fertile.

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[1] The best summary of the topography and geology of this country is that presented by Credner in his maps, which are schematic in their simplicity. (Anyone trained to observe geological relationships who has had the opportunity to fly over Thailand will have noticed the marked divergencies between the actual complexity of the stratigraphy and Credner's diagramatic delineations).

Intrusions of liquid magma occurred here and there in many places, forcing upward the sedimentary rocks; making many of the largest mountains of the southern, south-western and western rim of the Korat plateau; the main mountain masses of Northern Thailand; and those along the western border of the Kingdom, particularly from Chumporn south, where the intrusions are *en echelon*. The molten rock, being then still deep below the surface, cooled and hardened very slowly, so that there was time for the formation of large crystals; and so came into existence those granitic rocks, now exposed on Doi Suteb (Figs. 8, 9) and in many places in southern Thailand. In the south some of these granitic rocks contain crystals of tin ore; where these granites have weathered and been eroded away, the very heavy crystals of the tin ore have accumulated in valley bottoms. Not only is this material mined but the weathered granite itself has been mined, a procedure possible and practicable because of the very deep and thorough chemical decomposition of the rock.

In addition to the extrusions of dark igneous rock in Tamai, Chantaburi, in a few other places, as Nam awm, Kukan; Khao Kadong, Buriram; some of the south-eastern Islands; at Baw Ploi, Kanburi; and in the valley east of Lampang valley, there have been extrusions of a similar magma high in iron and similar elements, but low in silica. Hence these magmas hardened into very dark colored rock resembling basalt, which has weathered into a clay soil—red where the rainfall has been moderately heavy or heavy, but black in the dryer Buriram and Lampang regions. Associated with some of these magmas are zircon and other crystals so prized as semi-precious stones.

SOILS.

Though some of the characteristics of certain of the soils have already been stated, or hinted at, let us now consider the principal groups of soils somewhat more in detail, as well as some of the more general characteristics of soils.

As has been emphasized, soils are dynamic; they do develop and change, the amount and the nature of the changes depending upon a number of different factors. And as these features of the profile are best developed where there has been the least erosion,

some sorts of tropical soils, particularly laterites, are highly, in fact really too well developed in Thailand. "Too well" is used advisedly, for there are vast regions in Thailand where the country has too little normal erosion, particularly the sandy soils such as those bordering the central plain, which may be seen from the railway line east of Prachinburi and on to Aranya Pratet (Fig. 7). There are also vast areas in the Korat region where the weathering processes have dissolved and carried away almost all the plant food; where there were enough iron compounds in the parent material the laterite horizon has developed markedly. After studying soil and related agricultural problems in these regions in Thailand, I cannot help but agree with Mohr who has described laterite as "the bones of dead soil."

1. The Central or Bangkok Plain.

As already stated, these soils are annually flooded remarkably uniformly by the muddy water of the Menam Chao Phya. This deep, uniform, and gradual flooding, which makes ideal conditions for floating rice, adds a modicum of fertilizing silt annually to the soil. Close along the banks of the rivers and side channels the banks are higher and of lighter texture, such as silt loams and fine sandy loams, which make very good sites for houses, farm buildings, fruit trees, bamboo, gardens (Fig. 3), jute, etc. Back from the channels the soils are lower and a heavy clay (Fig. 4). In the southern part of the plain, along the gulf coast, considerable areas of these clay soils are still too saline for cultivation. On the other hand in some places in this plain, as in Amphur Ongkarak, Nakorn Nayok, the older alluvium appears to have been weathered free of most of the nutrients and there is no easy way to get fresh rejuvenating silt annually on to these lands.

In connection with rice soils, it may be mentioned in passing that as yet satisfactory and equally useful methods have not been developed for the study of soils which are normally submerged during the growing season of the rice crop, as have been developed in temperate regions for non-submerged, i. e. "upland" soils. There is great need for more specific methods for paddy soils, so that we can better understand what is going on in these soils while the crops are growing and so to be able to better evaluate methods for the management and the improvement of such soils.

Fig. 7. Shifting or caiñgin (*rai*) cultivation. In his clearing this farmer uses only a temporary shelter, because the white fine sand will produce only one crop of upland rice, sweet potatoes or melons before the fertility left by the forest is exhausted, and the land abandoned to forest again for five or ten years. Ban Mai Lai,, north-east of Rayong, South-eastern Thailand. November 1936. (RLP 724-12.)

Fig. 8. Upland rice is being threshed in this caiñgin (*rai*) in the forest on the slopes of Khao Sabab, Ban Ang, Chantaburi Province. Note the boxes with matting screens on three sides, into which the sheaves are whipped to remove the grain. South-eastern Thailand. November 1935. (RLP 527-5.)

While the clays of the Bangkok region are excellent for lowland rice, which in this part of the plain is transplanted and not broadcast, this soil, as many know, is far from being ideal for flower and vegetable growing! However, we must put up with this soil since we cannot afford any other, and we should understand at least something of its characteristics, in order to be able to handle it in the least difficult and most effective ways. First a few general considerations may be mentioned.

Organic matter, serving as the food or fuel for the microorganisms, and the humus or residue of the consumption of the organic matter by the microorganisms is an essential constituent of soils and contains a more or less concentrated essence of many plant food elements, a residue from the plants themselves as well as by absorption of substances from solution in the soil moisture. Hence for us gardeners, although burning of garden trash is the easy and neat way to dispose of waste organic matter, yet wherever possible soil and waste organic matter ought rather to be mixed together and kept in a neat heap, forked over occasionally, i. e. composted, so that the organic matter can react with the soil, improving it physically as well as chemically. The technique of composting has in the last few years been greatly improved, one of the best methods being the " Indore method " from the experiment station of that name, where the details were worked out by Sir Albert Howard. By this method even night soil and other pathologically contaminated materials can be safely and effectively used because of the temperature and aeration effects which eliminate the dangerous organisms.

Many sorts of organic manures need further fermentation processes to best fit them for quick and safe results in garden fertilization. But there is always considerable loss in such processes; for example, a ton of fresh manure may yield not even a quarter of a ton of " well-rotted " manure.

When one reads of the transportation in the United States of animal manures hundreds of miles for fertilization of gardens, and learns that some of the livestock fattening establishments in that country employ highly trained scientists to see that the best methods are employed for conserving the manure from the animal, so that it will be of the most value for fertilizer, one cannot help wondering

and being distressed at the casual unconcern with which our farmers in the Rangsit region tether their cattle on the canal banks and get rid of the manure by pushing it off into the water. Likely Thailand cattle manures are lower than average in plant nutrients because the available fodders are not rich to begin with; but even so, our farmers are really wasting a valuable substance, one which would be valuable to them on that land if they were to cultivate the same fields for a number of years in succession, but they will not likely cultivate the same land the next year. In many parts of the world tenant farming, especially with short leases, is one of the worst enemies of soil improvement.

Realizing the superior qualities of poultry manure, the Chinese gardeners of this city value duck manure particularly, and use it extensively, though it is noticeable that they do not handle it with sufficient care to conserve as much as they could of the fertilizing power. Chinese gardeners are skilled and they do get results but their empirical methods are not always the most economical in the conservation of plant nutrients. In China I noted that their methods of handling composts facilitate the loss of large quantities of ammonia nitrogen. The Chinese method of preparing oil cakes for application to their gardens by steeping in water until there has been considerable decomposition and much odor is evolved, is indeed effective. Here too, however, there is doubtless a considerable loss of nitrogen, the principal plant nutrient in this material. Be that as it may, we have to admit that their methods of managing the soil and producing crops of vegetables are by far the most effective for our soils and for the crops we can raise, and we can get many a hint from their methods until tried and proved better methods are developed. One thing we should not do is to bury the top soil under subsoil from the ditches or pits; it should not be too expensive to remove the soil, place the subsoil where wanted and then cover with the surface soil; certainly the final results would be better. And while the dimensions of the ridges and ditches might be profitably altered for certain crops, the methods of watering, the drainage, and the cultivation methods should all be considered. There is no doubt but that the annual cleaning of garden ditches and using the mud on the ridges both neutralizes the acidity and fertilizes the soil.

Fig. 9. Forest tree stumps and orange tree roots are being exposed more and more by the serious erosion of this loose, coarse sandy soil. Unless radical steps are soon taken, erosion will quickly destroy this promising young citrus garden. Ban Ang, Chantaburi province, South-eastern Thailand. September 1937. (RLP 826-4.)

Fig. 10. What little soil there is between the chunks of quartzite on this hill slope is poor and does not retain much moisture. The poor open hardwood forest is typical on such soils. Baw Ploi, northern Kanburi Province, western Thailand.

Moderate soil burning is a useful practice to reduce the stickiness of the soil, though the good effects are believed to last but three years. Of course, if the soil is burned hard it becomes brick or terra cotta, and of no more use as soil than bricks. However, nothing seems to be better for Anthuriums and some similar plants! Burning the soil by heaping some dry clods and finer earth on a thick layer of dry brush and leaves and setting fire to the fuel does reduce the acidity of the soil, as well as it intimately mixes ash with the soil, and so adds plant food to the soil.[1]

Certain commercial fertilizers, particularly the sorts which do not leave an acid residue in the soil, are of course effective, and in time large quantities of a number of kinds will doubtless come to be used in Thailand. With the possible exception of lawns, where it is difficult to add organic matter to the soil and the introduction of weed seeds is to be avoided, commercial fertilizers should not be allowed to replace the use of considerable quantities of organic matter in garden soil improvement.

2. THE NORTHERN VALLEYS AND SURROUNDING MOUNTAINS.

Between the mountains of sedimentary strata, forced up by the magmatic intrusions, are mountain valleys: Chiangmai and Fang; Lampang, Payao, and Ing; Prae, Nan, Pechabun, etc. Rivers draining these valleys have in almost all cases cut down the outlets and so now drain the basins quite well. The Ing valley is an exception in that the level of the outlet is determined by the level of the water in the Mekong River, so that in the Ing valley at certain seasons there is extensive flooding of the valley floor, greatly limiting the agricultural utilization of the land.

The adjacent steeper mountain slopes, as those of Doi Suteb, have lost most of their sedimentary strata by erosion, exposing and facilitating the still deeper weathering of the granitic core of the mountains. Much of the eroded material, particularly that which is coarser, has accumulated in the bottoms of the valleys, while the finer portions of the eroded material have been carried out and away by the rivers.

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[1] Hardon H., J., and J. Th. White: Gebrande aarde (Tanah Bakar) Korte Mededeeling van het Algemeen Proefstation voor den Landbouw. No. 14, 1935.

The higher mountain slopes have shallow soils, frequently stony, but even there the texture is often clay loam which is the result of thorough chemical weathering. However, profiles are not well developed, the soil eroding before it has been well leached of plant food substances. Hence these mountain soils are relatively much used for food and other crops, particularly by the mountain tribes who not only prefer the mountain climate for themselves, for their animals and their crops, but they also appreciate high mountain slope seclusion for the production of contraband opium (Fig. 16). Some of the lower hill and mountain slopes are of quartzites with shallow, very stony soils, and poor characteristic forest (Fig. 10).

Since in these valleys the river flood plains are made up of silts, to a considerable extent mechanically pulverized in the larger streams and rivers, the recent alluvial soils are quite fertile and productive. And where there is a good supply of water as in the Chiangmai plain two crops of rice are produced annually. If the soil material had been broken up and weathered chemically most of the plant foods would have been dissolved and carried away in the process. In the low water season the fine sandy loams and sands of the river banks and the broad shallow river beds themselves are often used for native tobacco and vegetable growing. These same sorts of pulverized materials together with the water of the rivers, leaching them as they flow, are the materials which maintain the fertility of the main central or Bangkok plain, as well as of the Ping, Yom, and Nan river bank soils between the mountains and the Nakorn Sawan Narrows.

Between the mountain soils and the flood plains, both in the northern valleys and in many places around the central plain, there is a zone of gently sloping, thoroughly weathered materials, developed mostly from the red beds and other fine sandy sedimentary and related materials (Fig. 7). These are the "poor lower slope sandy soils" as may be seen from the railway east of Prachinburi toward Aranya Pratet. These soils have had a fairly constant water table for a long period, and without much erosion, the profile development has proceeded to nearly the final stage; these are lateritic soils since they often contain a laterite horizon. In these soils the plant food content probably never was high, and has now sunk to a very low

point, as the poor, open, dwarf nature of the forest cover and the miserably poor yields of rice indicate. However, well irrigated and well fertilized, these soils can be used for special crops as well as for rice. Since these sandy soils superficially resemble the sandy soils of the Carolinas in the U. S., where the Virginia type tobacco is grown for flue curing, it has been supposed that similar fertilization here on these sandy soils would ensure the production of good Virginia-type leaf for flue curing. But apart from the very great difficulty in determining the exactly correct proportions and quantities of plant food elements needed by this sort of tobacco on this soil, with regard to plant nutrient quantities and proportions, tobacco is probably the most particular and sensitive plant man grows. The conditions of rainfall here make it very difficult if not practically impossible to successfully produce good curing leaf on these sandy soils. The important difference in the rainfall regime is that in the Carolinas the rainfall is gentle and very regular, while the rainfall here is apt to be very irregular and, when it does rain, it rains hard. When the rain fails to fall in time, the fertilizer concentration about the roots of the young plants is apt to be too high. When the rain does fall, the fertilizer is washed out of light unretentive soils too soon and most of it may be lost before the plant can use it.[1]

Here and there along the lower slopes of the hills and out on the valley floor there are bodies of darker colored loams. Incidentally, contrary to temperate zone experience, loam in the tropics is an unusual soil texture. These loam soils are quite fertile, well drained, and normally carry a mixed deciduous forest in which teak is the most important component. While the popular idea has been that all teak soils have been developed predominantly from limestone, this does not now appear generally to be the case. It is, however, noticeable that these teak forests are very much scattered, without any apparently definite distribution pattern. There is undoubtedly at times a relation between the teak soils and the underlying rock, but usually these are so deeply buried that the relationships have not been obvious.

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[1] The conclusions of Mr. M. M. Pittard, the American tobacco leaf expert, who has spent years and much money studying and developing Virginia type of tobacco growing in Thailand, as stated in a personal conversation.

Some valleys have rather divergent soil conditions. And most certainly other exceptional conditions will have been found when our surveys have been extended and our knowledge is less sketchy. Probably because of a better assortment of, generally, better rocks, *the Muang Löi Valley* has markedly better soils on the low hill slopes, which as a result have carried better forest. Caiñgin (rai) cultivation of cotton has long been successful in this valley, the region shipping down the Mekong by raft much cotton to lower reaches and to the Korat region. And it is in the Löi region that the cultivation of introduced cottons has been more successful in the last few years. The *Lampang Valley* has a relatively low rainfall and for some as yet unknown reason certain of the soils in the valley, back from the recent river deposits, have an unusually undesirable physical structure which makes them difficult to cultivate for upland crops; and the irrigation water supply has hardly been certain enough for paddy cultivation. And even for rice some of the Lampang valley soils have not been very satisfactory. Because of its isolation the soils of the *Pechabun valley* are not even yet well known. While there are considerable areas of the poor sandy lower hill slopes, in the lower valley there appear to be large areas of dark, clay soils. Farther north, especially on the eastern side of the river are large areas of light brown medium textured soils well irrigated and producing good yields of rice, sugar cane, and fruits.

3. The Northern Central Plain.

Between Paknampo to the south and Ampur Ban Tak and Utaradit in the north, this region has the following characteristics which resemble those of the main central plain: (1) The fertile, light textured river bank soils, for garden crops, are similar to but lighter than those further down the river. (2) The lower, heavier paddy soils, farther back from the rivers. These soils here suffer from rather stronger flooding when the rivers are high, for in this region above the Nakon Sawan Narrows the rivers rise and fall more rapidly than in the lower or Bangkok plain. (3) The poor laterite soils occupying much of the lower slopes of the hills and the vast region between the Ping river on the west and the Yom on the east. (4) The light grayish brown soils in the regions where the main rivers now debouche on to the plain from the mountains, as well as

along the former channels west of Bandara and Utaradit, and in the Sukotai region. (In the north-eastern part of the Bangkok plain similar bodies of soils have developed on the material brought out by the Pasak river, and north and north-west of Nakorn Patom are other bodies of similar soils brought out from the north-west by the Meklong (Kanburi) river).

This plain has one markedly different soil and agricultural condition, namely, the vast area of heavy, dark colored soils east of the Nan river, in the Pitchit and Pichai region, which is flooded deeply and rapidly in the rainy season and is very dry in the dry season. Much of the region is covered by tall grasses. These soils extend eastward some kilometers to the poor, lower slope, sandy, laterite soils. This region is too suddenly and too deeply flooded for rice growing in the rainy season, while in the dry season the soils are too dry and too hard to be successfully cultivated. A high level canal from the left bank of the Nan river, where it comes out of the mountains east of Ta Sao by irrigating this region from the east, and by the carriage of silt out on to the poor sandy soils, might make this region productive.

4. THE KORAT REGION.

The topography is hardly that of a plateau in the strict sense; rather it is that of a gently sloping region with the fall from the west and the south-west toward the east. Around the south and the west the sedimentary rocks have been raised up by the intrusions, the granites of which are exposed in a few places in the mountains. And in the south-west limestones and other rocks, giving rise to better, heavier and darker soils than do the quartzitic sandstones, are exposed and have given rise to the heavier and darker soils which have been carried out by the streams past Nakorn Rajasima and on to the east. South-west of Sakon Nakorn, in the north-east and eastern regions are lower hills mostly of quartzitic sandstones. For the most part the sedimentary rocks as exposed in streams and railway cuttings are only slightly disturbed, lying nearly horizontal.

The undulating to rolling surface topography of much of the region is occupied by fine sandy lateritic soils. Long weathered and deeply leached, what little plant food was originally in the parent

materials has been largely leached out. The higher portions are for the most part occupied by a poor, open forest of hard woods, while the depressions, where enough but not too much rain water can collect, are used for paddy, yielding very low amounts of grains, too often only 2 or 3 buckets (*Tang*) per rai, not often as much as 10, and extremely rarely as much as 20 buckets per rai. On the forest soils, which normally do not flood, caiñgin cultivation of native cotton is quite common, most of the families each having a small patch, on newly cleared forest each year, for their own ginning, spinning, and weaving. After the single year's cotton crop the land is allowed to revert to forest for a number of years. Tobacco for family use is grown on some small plot convenient to a water hole, or pond, or well; the plot is heavily manured with cattle manure, frequently several times during the season. The same tobacco plot is used year after year. Mulberry bushes for rearing silk worms are also grown on a permanent plot near the house where the soil is more fertile; additional manure is applied annually. Particularly in the flatter portions of the region, where there is not at least slightly higher forest land to be cleared, the richer, heavier soil of the termite heaps is planted with cotton. Very generally red peppers, egg plant and string beans are planted on these mounds, and tobacco also. Where seed is available, a few pigeon pea plants may be planted about the house. The local cordage fiber *Paw Gao* is from the stripped bark of a tall annual *Hibiscus*.

Cattle play an important part in the concentration of plant nutrients so that the above-described cropping system can continue. Cattle pasture in the forests, but at night are kept in the coral under the house. The manure so collected is necessary for the mulberry and tobacco crops.

As recently pointed out,[1] one of the important features of the caiñgin system is that the tree roots go deep down and bring up nutrients from far below to help enrich the surface soil. This same effect is obtained in this region where there are several sorts of trees

[1] Pendleton, Robert L. Some interrelations between agriculture and forestry, particularly in Thailand. Journal of the Thailand Research Society, Natural History Supplement *12*, 33—52, Plates 8. 1939.

Fig. 11. Taking a soil sample from this poor rubber plantation 16 kms. north of Taptieng, Trang Province, southern Thailand, to try and find why the Hevea trees grow so very poorly. These trees, more than 15 years old, are hardly larger than normal 6 year old trees. October 1936. (RLP 694-9.)

Fig. 12. This vigorous stand of young Hevea rubber trees, with a good ground cover indicates a suitable soil and good care. Along the Huey Yawt road, about 20 kms. north of Taptieng. Trang province, Southern Thailand. October 1936. (RLP 694-11.)

which are desired in the paddy fields, for paddy yields are noticeably higher than without the trees. The tree roots collect the plant food not only from deep down in the soil but also from materials percolating into the soil at the first rains, before rice can be planted out; the trees hold it and give back a major portion of it in the dead leaves, flowers and fruits, etc.

The hills with the more active normal erosion and the shallower, stony soils, less leached, are more extensively used for crops other than paddy—crops which will not grow on the more thoroughly weathered, poorer lateritic soils.

The one occurrence known of red clay (tropical loam) is in Kukan province, where some of the forest is cleared and cotton planted. This soil would be useful for food crops, but being in the forest a food crop would be too likely to be destroyed by the wild elephants of the region. Villagers there complain that because of the elephants their villages are poor.

Particularly along the main rivers are some vast uncultivated plains such as Tung Gula Rong Hai (Fig. 13). Not only are the soils poor but, when the water is in flood, it is deep, and when the water recedes, the soil is too dry. Moreover, the grass on these plains is so poor and unpalatable that the cattle do not relish it.

In many places in the Korat region there is considerable sodium chloride in the sandy soils. These salts are believed to have come from the accumulations present in the Red Beds. Near Udorn, for example, salt springs flow directly from the red sandstone located a few meters below the surface. Credner believes that the depressions here and there occupied by ponds are the result of the dissolving out of salt lenses in the underlying sandstones; this has allowed the overlying materials to subside.

5. SOUTH-EASTERN THAILAND, INCLUDING THE ISLANDS.

Important among the soils of this region are the sandy soils from granitic materials which occupy the long low slopes of the hills south-east of Cholburi and eastward. Well watered with a high water table, yet with fairly good drainage, this region has been noted for its sugar cane which, together with rice, is extensively grown. Farther south-east, in the Chantaburi region, among the granite moun-

tains Khao Sabab is the best known. Its soils, largely from granite, and with a heavy rainfall and good drainage, have proved adapted to the growing of fruit and of Hevea rubber. Erosion is a serious menace, however (Fig. 9.).

Here as in the Korat region are great expanses of the comparatively infertile, fine sandy, light colored, lateritic soils. The topography is perhaps not generally flat enough and the parent materials are generally too poor in iron compounds to permit any very general development of a laterite horizon. I say "perhaps" for most of this region has not been explored pedologically.

In some of the river and stream valleys particularly toward their mouths, as at Tamai, Ta Chalep, Klung and Trat, the salt water estuaries are being filled by heavy, dark clays. As the land extends farther, pushing back the sea, the excess sea salts leach out so that these soils produce good crops of paddy (Fig. 2). The conspicuous and unusual body of dark igneous rock between Muang Gao and Tamai has weathered deeply to the red clay, so well known for the production of black pepper (Fig. 6). This soil, feeling more like a loam, can be cultivated within an hour or so after more than an inch of rain has fallen. Physically excellent, and an exceptionally good medium for plant growth, the at most very small amounts of nutrients, which this soil actually contains and can supply to the plants, necessitates heavy fertilization for the production of pepper and other strong feeding crops. Farm yard manure is essential; and "soil burning" is extensively practised. Since the price of pepper has been very low for some years, the farmers are neglecting their pepper vines, for the cash return from the sale of the pepper no longer pays even for the cost of spray materials and for the extra labor which must be hired for tying the vines to the posts. Hence most gardens have been neglected, and much of the land has been converted into rambutan and Hevea rubber gardens, plants which can get along with much less plant food available in the soil.

The earth is "burned" by making a long, flat heap of brush and other fuel, about a meter high 3 meters wide, and perhaps 8 to 10 meters long. On this fuel is heaped as much of the loose granular clay as possible. The fuel is lighted and smoulders for many days; and from time to time the soil already heated, around the edges is

raked away, allowing more air to reach the fuel. After cooling, the burned earth which is mixed with ashes and has undoubtedly absorbed ammonia and other substances from the smoke, is mixed with cattle manure and is buried near the roots of the pepper vines. As has been shown in Java, the burning markedly reduces the acidity of the soil as well as adding nutrients.

Around the edges of this body of red soil a thick laterite horizon has developed and now in places (Hin Dat) is exposed and appears as irregular masses of dark brownish black pavement. In this region laterite has been used extensively as a construction material. At least a century and a half ago the then new capital of the region, now known as Muang Gao, was built on the bluff overlooking the river plain to the east and the harbour to the south. The still standing heavy walls of the town are of laterite blocks. But where these blocks were actually quarried is not now known. Over beyond the river on some slightly elevated lands, (the relics of an older, little higher valley floor), are modern laterite quarries. Laterite blocks are still being used for well curbing and other masonry construction.

Farther down the coast, on the other side of Khao Sabab, in the Trat region there are areas of laterite soils of which the surface soil is so very shallow as to be practically useless for plant growth. On the other hand along the main river to the north of Ampur Khao Saming are narrow strips of higher, better soils which formerly grew pepper, but which now have been abandoned to bamboo.

The islands of the south-eastern coast have soils somewhat different from those of the mainland. Gaw Chang, aside from the steep mountains, has some few sandy paddy soils; Gaw Kradat soils are mostly sandy, with some coraline detritus, though the core of the island is of basic igneous material which has weathered into a red clay laterite soil—laterite is exposed as reefs along the shores of the island in several places. Gaw Gut, on the contrary, is mostly of horizontally bedded sandstones which have given rise to the usual light fine sandy soils.

6. SOILS OF SOUTHERN THAILAND.

In this region in general are subdivisions of soils similar to those which have already been described. The following are the

principal soil groups of peninsular Thailand : (1) The river flood plains, usually of very limited extent. Particularly in some places these coalesce with (2) the shore deposits. These are made up of two distinct sorts of soils which alternate with each other in long narrow bands; (2a) long sandy ridges parallel with the shore, which are former beach lines. Between these sandy ridges are the (2b) swamps which gradually fill with river sediments to make the long low and often narrow strips of paddy soils. Behind these shore deposits and between the river flood plains are (3) the more or less peneplaned sedimentary formations previously mentioned, of which the striking limestone bluffs are about the only feature of the parent rocks still visible (Fig. 1). Where there is sufficient place on these limestones for soil accumulation from the limestone, there have developed (4) red clays, often gravelly with small iron concretions. Farther back from the coast, behind the peneplaned and in places laterized sedimentaries are the (5) light clay loam lower hills and slopes, weathered from certain metamorphic rocks, as found in the Yala region. These soils are most suitable for the growing of Hevea rubber (Figs. 11, 12). The related lateritic soils, gravelly with iron concretions, as found along the Penang road near Sadao, are also much desired for rubber planting. Still farther back from the sea are (6) the steep stony loams on the mountains. These soils are usually a light brown with a surface portion darkened with organic matter down for a number of centimeters. Here and there (7) are flat grassy plains, sometimes a number of kilometers in extent, which have developed on formations (1) and (3). These dark acid soils have not been used successfully for paddy without the addition of guano or some other phosphatic material. And rubber planted on these soils is hopelessly stunted. For the most part these soils are utilized only for pasture.

On the old sandy beach ridges in places are (8) podzols, typical except that they have a profile with magnified dimensions.[1] Of practically no agricultural value, and in this country of such limited area

[1] A podzol is a kind of soil that until recently was supposed to be formed only under temperate humid conditions. The profile is characterized by a black surface organic layer, under which is a clean white bleached sand horizon about 1/4 m. thick ; this is underlain by a firm brownish black or coffee colored horizon of precipitated organic matter somewhat cemented with iron compounds.

Fig. 13. Tung Gula Rong Hai, a vast plain north of the Lamoon river, in north-eastern Thailand. While these infertile soils will not raise even a good growth of grass, when the plain is flooded for some months in the rains, fishing is important. Sawanapum Amphur, Roi Et province, north-eastern Thailand. March 1940. (RLP 1235-11.)

Fig. 14. Because this soil is adapted to growing tobacco for flue-curing, much of this excellent grove of teak in Chiengsan, has already been destroyed. Tobacco grown from Virginia seed in the foreground. Chiengrai Province, extreme northern Thailand. December 1938. (RLP 1062-12.)